TOWARDS CDIO STANDARDS 3.0

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ABSTRACT

The topic of this paper is the CDIO Standards, specifically the formulation of CDIO Standards version 3.0. The paper first reviews the potential change drivers that motivate a revision of the Standards. Such change drivers are identified both externally (i.e., from outside of the CDIO community) and internally. It is found that external change drivers have affected the perceptions of what problems engineers should address, what knowledge future engineers should possess and what are the most effective teaching practices in engineering education. Internally, the paper identifies criticism of the Standards, as well as ideas for development, that have been codified as proposed additional CDIO Standards. With references to these change drivers, five areas are identified for the revision: sustainability, digitalization of teaching and learning; service; and faculty competence. A revised version of the Standards is presented. In addition, it is proposed that a new category of Standards is established, "optional standards". Optional Standards are a complement to the twelve "basic" Standards, and serve to guide educational development and profiling beyond the current Standards. A selected set of proposed optional Standards are recommended for further evaluation and possibly acceptance by the CDIO community.

KEYWORDS

Sustainable development, Digitalization, Learning environments, Faculty competence, Standards 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

The CDIO Standards were introduced in 2005, with the main aims to (a) clearly describe the key features of CDIO programs and (b) to support the continuous improvement of CDIO programs through the use of a capability maturity-based self-evaluation process. The creation of CDIO Syllabus version 2.0 and of CDIO Standards user experience influenced the development of CDIO Standards 2.0 and 2.1, although the updates were minor.

In recent years, a number of educational change drivers have emerged, including the recognition that engineering education plays a critical role in creating a sustainable society and the abundance of digital learning tools. In addition, a number of CDIO schools have developed approaches that go beyond the original scope of the CDIO Standards. Considering these developments, there is a need to review and update the CDIO Standards.
This paper thus aims to argue and propose modifications and additions to the CDIO Standards, accommodating the needs of the CDIO community on two levels:

We first discuss and propose general updates to the Standards 2.1 on a level that reflects widely shared and recognised needs. These changes should be generally acceptable, and of such nature that CDIO will otherwise be seen as incomplete or falling behind. Second, in order to serve the needs of more progressive institutions, and to keep the position as thought-leaders in engineering education, other changes are addressed in new optional standards.

The general update addresses Standards 1-12 and considers the following topics:

- Sustainable development
- Digitalisation & learning environments
- Services
- Faculty competence

In the second part of the paper, we summarize what some progressive institutions are doing. These developments reflect educational components beyond what can presently fit in CDIO as a general framework. It is proposed that introducing a new category of Standards, called "optional" Standards is a way to address this issue. However, the formulation of new optional standards must keep the interplay with the existing standards in mind, and the proposition and acceptance by the CDIO community of new (optional) standards need to be carried out in an open, transparent and structured way.

ORIGIN AND EVOLUTION OF THE CDIO STANDARDS

The CDIO Standards are a key part of the CDIO framework by defining the distinguishing features of a CDIO program, by serving as guidelines for educational reform, and by providing a tool for continuous improvement (Crawley *et al.,* 2014).

The CDIO Standards were initially presented in 2005 (Brodeur & Crawley, 2005) and described more fully by Crawley *et al.* (2014). Rubrics for evaluating programs according to the Standards were introduced in 2010. The CDIO Standards have since been updated to version 2.0 (Crawley *et al.*, 2014) and the rubrics have been further modified (Bennedsen *et al*., 2016). These modifications have been relatively minor and have not changed the scope or the main contents of the Standards.

While the CDIO Standards have been stable during this time period the internal and external context of engineering education has evolved.

External change drivers

Three types of external factors that drive changes to the CDIO framework can be identified, stemming from changes to the **context**, the **what** and the **how** of engineering education: First, new characterizations of the context that future engineers will operate in are constantly being published. If the context changes, engineering education will need to follow and adapt. The need context for engineering is often summarized by the term “VUCA”, an acronym for Volatility, Uncertainty, Complexity and Ambiguity (Wikipedia, 2019b). An engineering education that prepares for a VUCA world will likely have a much stronger emphasis on multidisciplinary projects, addressing real-world, open-ended design problems. A second change driver comes in the form of updated notions about what the goal or what of engineering practice is. The UN goals for sustainable development (United Nations, 2015) challenge engineering programs to broaden the taught goals for engineering, i.e., from optimizing technical and economic performance to the simultaneous achievement of goals for economic, environmental and social sustainability. Addressing this challenge requires updates to disciplinary knowledge, skills and attitudes to be learnt in engineering education. A third category of external change drivers is rooted in descriptions of current and emerging best practices for engineering education (“how”). According to Graham (2018), future leaders in engineering education offer programmes with four key characteristics: a combination of digital and student activating learning forms, educational arrangements with a high degree of flexibility and diversity, global and multidisciplinary elements, as well as design projects that at the same time offer opportunities for reflection on technology development and own learning.

Internal change drivers

In addition to external change drivers, the CDIO framework is also subject to challenges initiated from within the CDIO community, either as criticism resulting from theoretical analysis or practical experience of the framework or as developments of novel education approaches or tools. Criticism includes observations that while the CDIO framework supports many of the activities that are required to prepare for a EUR-ACE accreditation, there are also some missing elements, for example concerning standards for student support (Malmqvist, 2012). Respondents to the global CDIO survey (Malmqvist *et al.*, 2015) identified faculty competence as a major barrier to successful CDIO implementation and mentioned insights into internal motivation and gender and sexual diversity as poorly treated in the

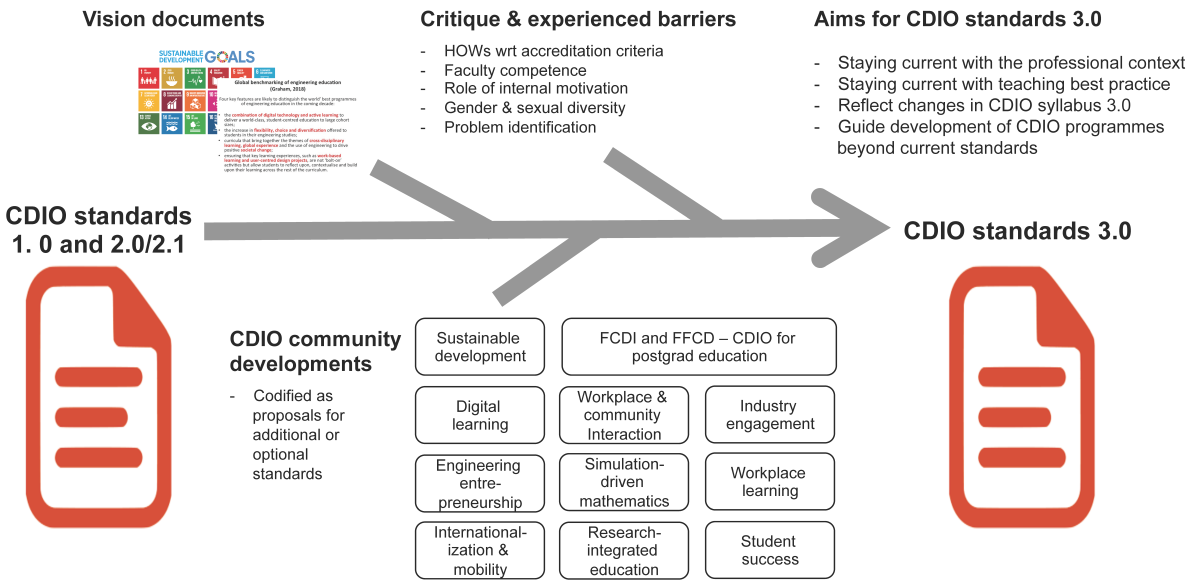

Figure 1. Revision of the CDIO Standards to version 3.0.

CDIO Syllabus. Taajamaa *et al.* (2016) and Kohn Rådberg *et al.* (2018) argue that CDIO should put a stronger emphasis on problem identification, not only on problem-solving. The second type of internal change drivers is constituted by proposals for additional or optional standards. The first proposal for an additional standard was the "Internationalization & mobility" standard (Campbell & Beck, 2010). Malmqvist *et al.* (2017) introduced the concept of optional standards along with six candidates for such standards. In 2018, proposals for optional standards related to workplace learning and industry engagement (Cheah and Leong, 2018); for student support (Gonzales *et al.*, 2018), and for master and doctoral level CDIO programs (Chuchalin, 2018) were published.

The inputs to the process of revising the CDIO Standards are summarized in Figure 1

REVISING THE STANDARDS TO CREATE VERSION 3.0

In this section, we outline and motivate the modifications proposed to evolve the CDIO standards from version 2.1 to version 3.0. A statement of the aims for the revisions, and analysis of some challenges that need to be considered precede the discussion. The modifications are then summarized. The modified standards are found in the appendix.

Aims for revision

There are three main aims for this proposal for revision of the Standards to version 3.0:

- To accommodate changes in the external context of engineering education, as interpreted in the updates of the CDIO Syllabus
- To stay current with the developments of teaching best practice
- To provide guidance for the development of CDIO programmes beyond current Standards

Further, the intent is to carry out a transparent revision process through the publication and presentations of proposals (such as this one) in open CDIO meetings, while at the same time making sure that the evolving standards build on the original intent and do not grow in an uncontrolled fashion.

Challenges & considerations when updating the Standards

Below, we will discuss specific proposed changes to the CDIO Standards. However, let us first outline some challenges and pre-requisites that have been considered.

The Standards are formulated rather broadly and generically. This allows flexibility for how something is carried out, but also makes it more complicated to add or evolve the Standards. When it comes to changes in **what** the education addresses, it is relatively easy to make the argument that “X is already covered” if it is included in the Syllabus. However, not all readers simultaneously access the Syllabus and the Standards hence may get the impression that the Standards do not address certain current topics. In the proposal below, this is reflected in two ways: Some moderate changes to the standards to reflect the evolving context of engineering education is proposed, whilst no additional basic standards are proposed. The concept of optional standards is suggested as a way to explicitly accommodate more specific topics.

As noted, some Standards refer back to the Syllabus, indicating a need to revise the Syllabus rather than the Standards. This principle is adhered to here as well. In some cases, however, changes apply to both documents. For example, the stronger emphasis on sustainability in the Standards is aligned to corresponding revisions of the Syllabus (see Rosén *et al.*, 2019).

The Standards are organized in a flat structure, as a list. In principle, adding elements to standards or new standards could be done expanding the scope of some current Standards, by breadth (introducing Standard 13, 14, …) or by depth (introducing Standard 5.1, 5.2, …). In the proposals below, some Standards (6, 9) are expanded, whilst the concept of optional standards can be viewed as an addition by breadth. The introduction of a hierarchy is a possibility but is not pursued here.

The original scope of the CDIO Syllabus and Standards essentially focused on common denominators for learning outcomes for a first degree in engineering (bachelor or master, depending on country). Later proposals (e.g., internationalization, leadership, student support) have been associated with expansions on that scope. Below, it is argued that such proposals should be accommodated as optional standards.

Suggested revisions

Sustainable development

The CDIO Syllabus 1.0 received some criticism for not incorporating sustainability adequately. Competences for sustainable development were in fact included in CDIO Syllabus 1.0, but did not appear explicitly in the higher levels of the Syllabus. In the CDIO Syllabus 2.0 development, sustainability was nevertheless reconsidered, with a strengthening of topics and clearer visibility of sustainability on the top levels on the CDIO Syllabus. For example, a new section 4.1.7 Sustainability and the Need for Sustainable

Development was added, and the term “environment” was included in the headings on section 4 and 4.1 (Crawley *et al.*, 2014).

However, the overarching goals of engineering products and systems (e.g. high quality, low cost, efficiency etc.) are, with the exception of one use of the word “value-added”, not embedded in the CDIO Standards, neither in version 1.0 nor 2.0/2.1. The reason is that the Standards describe **how** the CDIO Syllabus learning outcomes can be achieved. Hence, since goal statements are considered as **whats**, the inclusion in the CDIO Syllabus would lead to a follow on-effect: If sustainability topics are more strongly featured in the CDIO Syllabus, then it would follow that achievement of Standards 2 and 3 would also require a more extensive coverage of sustainability in the curriculum. This content-focused argument does, however, not address the visibility aspect. A reader who does a stand-alone reading of the CDIO Standards 2.0/2.1 may not fully comprehend the Syllabus-Standards coupling. In light of the importance of the topic, we, therefore, argue that it is motivated to revise the CDIO Standards in order to bring forward the terms “sustainability” and “sustainable development”.

In the appended proposal for CDIO Standards, these revisions have affected Standards 1, 3, 4, 5 and 9.

Sustainable development has also been proposed as an optional standard (Malmqvist *et al.*, 2017). For this topic and some others, including entrepreneurship, it has been argued that an optional standard is unnecessary. The argument is either that the topic is already covered in the CDIO Syllabus and, hence, although not explicitly, also addressed by the CDIO Standards. The appropriate approach would then be to first revise the CDIO Syllabus and then the core CDIO Standards to accommodate the topic. However, an optional standard offers an additional level of concretion in terms of guidelines for learning experiences and for evidence of fulfilment that can be helpful in curriculum design and when marketing the profile of the programme. We, therefore, suggest that some elements of the proposed sustainable development standard are integrated into Standards 1 and 3, but also that the sustainable development standard be kept among the proposal for optional standards.

Digitalisation & learning environments

While sustainability can be understood to be the central objective and constraint for future engineering activities, digitalization can be argued to be the major enabler for reforming both engineering work and ways of learning how to engineer.

The CDIO Standard 6 “Engineering workspaces” focuses explicitly on physical workspaces, emphasizing hands-on and social learning. Such learning spaces are essential for CDIO learning but tended to be threatened or even lacking during the early 2000s. The recent emergence of Makerspaces and FabLabs as a distinctive feature of “current leaders” in engineering education (Graham, 2018) has again established the importance of such spaces. However, Graham (op. cit.) also observes that learning environments at “emerging leaders” in engineering education are based on a purposeful combination of digital learning and physical learning environments that support work-based learning and user-centred design projects.

We, therefore, propose a significant revision of CDIO Standard 6. The name is modified to “Engineering learning workspaces” in order to emphasize that these spaces, physical and digital, support both student engineering work and learning in a broader sense. The description and rationale of Standard 6 can be constructively complemented with elements adapted from the previously proposed optional standard "Digital learning" (Malmqvist *et al.*, 2017), which we further propose to be integrated into Standard 6, *i.e.*, not pursued as an optional standard.

Services

According to Crawley *et al.* (2014) page 50, the goal of engineering education is that every graduating engineer should be able to:

Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.

This formulation can be used as a "working definition" of what engineers do, and it forms the basis for the entire CDIO framework. However, during the last decade or so, the development and operation of services have emerged as an important aim for engineering. Service has a very wide interpretation, and e.g. the explanation in Wikipedia says "*A 'service' can be described as: all intangible effects that result from a client interaction that creates and captures value"*. For simplicity, the discussion here will be restricted to services where engineering is involved in some way. It should be stressed that engineering work to provide services of various types has existed for many years in terms of e.g. professional services (engineering consulting), or supply of electricity with stable voltage and frequency and water of sufficiently high quality. More recently an important driver for the growing importance of services is the rapid development within information and communication technology (ICT), and services such as bandwidth, computational capacity, and data storage are parts of the daily life. The arrival of the smartphone with the possibility to download applications (apps) for different purposes has enabled a tremendous growth of ICT based services. A parallel to the service bandwidth, but within another field, is for a customer to buy transportation capacity (mass times distance per time unit) instead of purchasing a new heavy truck. Thus, in addition to the words product, process, and system in the definition, the word *service* has become more and more common and relevant for engineering and engineering education in various ways. The impact is also visible in mechanical product development textbooks, such as Ulrich & Eppinger (2015), which now include chapters on service design.

The main implication for the CDIO Standards of the growing importance of the service area is to append the word *services* in the definition above and hence also in Standard 1 which contains a similar formulation. Such a change will then have implications for e.g. Standard 5, which talks about the development of products and processes, and here the scope needs to be widened to include services. In addition, services should be added to the sequence product, process, and system also in Standard 9 and others. In summary, the Standards 1-7, 9, and 11 are affected by this modification.

Faculty competence

Standards 9 and 10 address enhancement of faculty competence, with regards to the same *engineering skills* that they should help students develop (**what**) and the *teaching competence* to enable the development of education according to the CDIO standards (**how**). Edström (2017, p. 81-82) pointed out that this leaves CDIO silent on the matter of faculty competence regarding the theoretical content, despite the fact that *deeper working understanding of technical fundamentals* is the first aim of CDIO (Crawley *et al.*, 2014, p. 7). Adding to this, faculty members are increasingly tasked to integrate learning of sustainability and ethics with learning subject matter content. Edström further argues that it is not enough that the faculty should know the subject for themselves, but they must also be able to guide others into understanding it. Shulman (1987) coined the concept pedagogical content knowledge, “*the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction*” (p. 8).

A complete conceptualisation of faculty competence contains two aspects related to the **what** – one aligned to the professional preparation and one to the disciplinary knowledge. We do not propose adding a standard but suggest that faculty competence in advanced disciplinary knowledge, by which is meant pedagogical content knowledge, is added to Standard 9.

OPTIONAL STANDARDS

The concept of “optional CDIO Standards” was introduced by Malmqvist *et al*. (2017). Malmqvist *et al.* (*op. cit.*) argued that while the original twelve Standards (referred to as “basic” Standards) have shown to be a robust and still relevant benchmark for the core of a first engineering degree, emerging and evolving expectation on the competences of graduating engineers as well as new pedagogical approaches and tools motivate the extension of the CDIO framework, in the form of additional Standards. The basic CDIO standards form a core to which optional CDIO standards can be added to indicate a particular profile or development direction for a program, but the optional standards do not replace any of the basic standards.

An optional CDIO Standard will be used for the same purpose as a basic, i.e., as a support for program design, for period program review and for benchmarking. Malmqvist *et al*. (*op. cit.*) further put forward a number of requirements that an optional Standard should fulfil. An optional CDIO Standards should:

- Address an important, typically emerging, need in engineering education.
- Be based on a novel, yet well codified, pedagogical approach, developed within or outside of the CDIO community.
- Be widely applicable, i.e. not be specific to a single discipline (e.g., civil engineering).
- Not be sufficiently addressed by interpretation of a current standard (such as integrated learning).
- Reflect a program-level approach, and not be obtainable by implementation in a single course
- Be evident in a substantial number of CDIO programs as a distinguishing feature.
- Support the definition of a distinct program profile, beyond basic CDIO.
- Be assessable by the CDIO standards rubrics.

Current proposals

Table 1 summarizes the current set of proposed optional Standards, 11 in total. Roughly, they can be divided into three groups: Some proposals are linked to major societal trends that are high on the strategic agendas of many universities and companies: Sustainable development, Digital learning (we include Simulation-based mathematics here) and Engineering entrepreneurship. Another group has the common trait of outreach and collaboration: internationally, with research, with companies or the local public sector. Some proposals also aim to expand the scope of the Standards, either towards student services and support or towards graduate education.

Table 1: Proposed optional standards

Title		Short description	Source
Strategic trends	Sustainable development	A program that identifies the ability to contribute to sustainable development as a key competence of its graduates. The program is rich with sustainability learning experiences, developing the knowledge, skills and attitudes required to address sustainability challenges	Malmqvist *et al.*, 2017
	Digital learning	Engineering programs that support and enhance the quality of student learning, and teaching, through digital learning tools and environments	Malmqvist *et al.*, 2017
	Simulation-based mathematics	Engineering programs for which the mathematics curriculum is infused with programming, numerical modeling and simulation from the start	Malmqvist *et al.*, 2017
	Engineering entrepren-eurship	Engineering programs that actively develop their graduate's abilities to, in addition to conceive, design, implement and operate complex products, systems and processes, to commercialize technology and to create business ventures based on new technology	Malmqvist *et al.*, 2017
Outreach & collaboration	International-ization & mobility	Programs and organizational commitment which exposes students to foreign cultures, and promotes and enables transportability of curriculum, portability of qualifications, joint awards, transparent recognition and international mobility	Campbell & Beck, 2010
	Research-integrated education	Engineering programs that include one or more research experiences as part of student learning	Malmqvist *et al.*, 2017
	Industry engagement	Actions that education institutions undertake to actively engage industry partners to improve its curriculum.	Cheah & Leong, 2018
	Workplace learning	A curriculum that includes students working in a real-world work environment with the aims of strengthening in-campus learning and developing their professional identity.	Cheah & Leong, 2018
	Workplace and community integration	Engineering programs that actively develop their graduates' abilities to identify and address authentic and open-ended problems, in authentic settings, interacting with stakeholders	Malmqvist *et al.*, 2017
Expanding scope / coverage	Student success	A curriculum supported in the analysis and synthesis of information allowing taking effective actions to mitigate the risk and vulnerability in the student population; with strategies focused on the prevention of drop out and that guarantee student success.	Gonzales *et al.*, 2018
	Foresight – Forecast – CD(IO)	Revision of all CDIO Standards to fit frame of master and PhD programmes. This implies elaborating on product (etc) lifecycle stages prior to Conceiving, referred to as Foresighting and Forecasting	Chuchalin, 2018

Process for evaluating and approving proposals for optional Standards

Figure 2 outlines a process by which a proposal for an optional CDIO Standard can be evaluated and possibly approved.

The starting point is that a proposal for a new optional Standard has been formulated by one (or several in collaboration) CDIO universities. The proposal should be documented in a paper that is submitted to the annual international CDIO conference, be presented there, and published in the conference proceedings.

In conjunction with the international conference, the CDIO Council will review proposals for new Standards. They can give three different recommendations:

- "Reject", implying that the proposal is not assessed as suitable for the status of an approved CDIO Standard.
- "Approval for potential revision of basic Standard", indicating that the proposal is assessed to have merit, but that it is positioned too close to an existing Standard in order to motivate the addition of a new Standard. Therefore, the proposers are tasked with creating a revised version of an existing Standard, in which their ideas are integrated.
- "Approval for evaluation as new optional Standard", meaning that the proposal is of sufficient distinction and quality that it may potentially be accepted as a new official CDIO Standard.

If the Council recommendation is "Approval for potential revision of basic Standard", then the next step is that the proposers are tasked with authoring a revision of an existing Standards, in which their ideas are incorporated.

If the Council recommendation is "Approval for evaluation as new optional Standard", the proposal will be distributed to all CDIO member universities for evaluation and feedback. The Council will summarize the feedback and provide instructions to the proposers on how the proposal should be revised in order to address the feedback.

The CDIO Council will review the revised proposals during the following year's international conference. If accepted, the new or revised Standards will be included in the official CDIO framework and published on www.cdio.org.

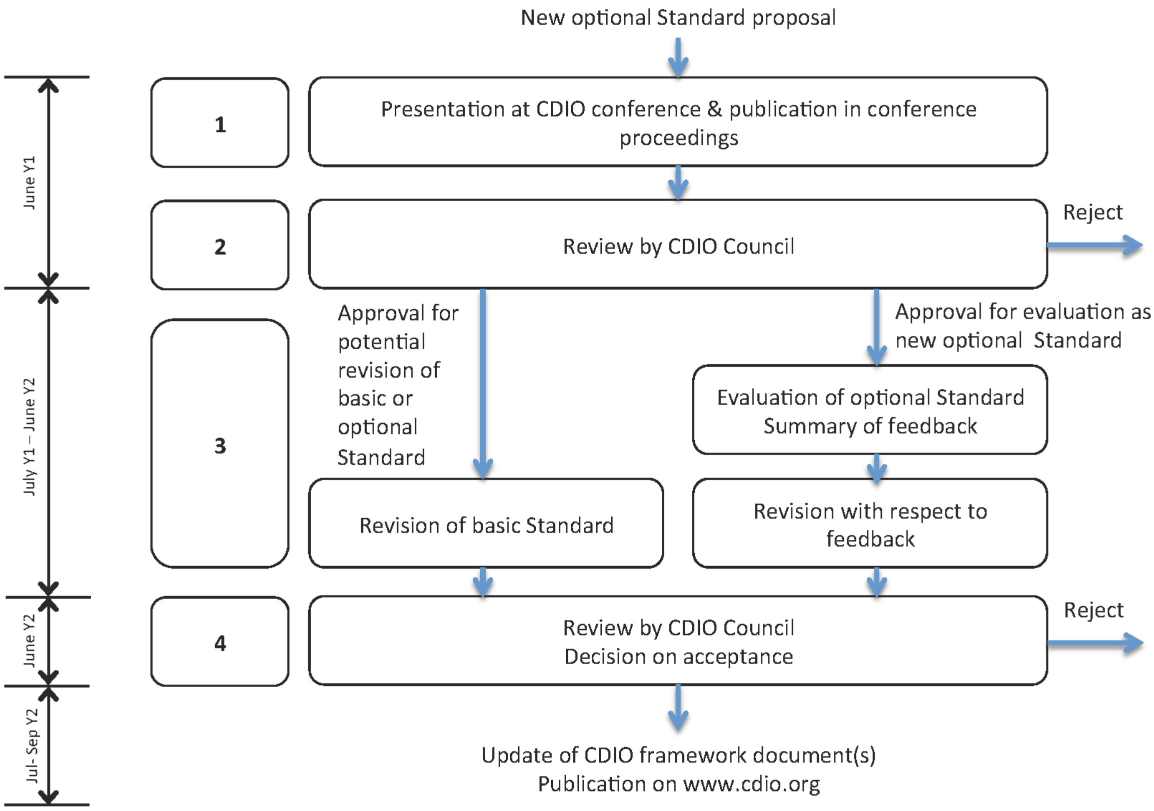

Figure 2. Optional Standards evaluation and approval process.

CONCLUSIONS

Changed perceptions of the role of engineering and education development efforts motivate a revision of the CDIO Standards from version 2.1 to 3.0. The revisions should address sustainability, digitalization of learning, service engineering, faculty competence and the attitudes that students are expected to develop during their studies. As a consequence, many of the CDIO Standards should be updated. However, the most significant changes affect Standard 1 – The Context, Standard 6 – Engineering Learning Workspaces (new name) and Standard 9 – Faculty Competence. The mentioned modifications are to a high degree driven by external factors.

Internally, many development efforts undertaken by CDIO universities have been codified in the same format as the original Standards. The dissemination and wider adoption of these proposals warrant the introduction of a new category of Standards, referred to as “optional” Standards. The optional Standards serve to guide educational development beyond the scope of the original, “basic” Standards. A number of such optional Standards can be identified. A suitable next step is to evaluate these through an open review in the CDIO community. Given a positive evaluation and possibly some adjustments, an optional Standard can be approved by the CDIO council and officially included in the CDIO framework, as available on www.cdio.org.

During the development of the proposal for revised standards, it was also observed that fosterage of values and attitudes have become more prominent goals for engineering education. Indeed, the CDIO syllabus identifies many desirable values and attitudes, including, e.g., self-awareness, perseverance, and integrity. However, there are to date no CDIO standards that suggest how to develop such values or attitudes, neither specifically nor in a general sense. An investigation into the feasibility of creating standards for how to form engineering values and attitudes is an interesting area for future work. Another needed future effort is the revision of the rubrics for the basic standards along with the elaboration of new rubrics for accepted optional standards.

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APPENDIX: PROPOSAL FOR CDIO STANDARDS 3.0

The proposal for revised standards follows below. The revisions are yellow-marked. The intent is to facilitate discussion and feedback on the proposed changes, prior to the ultimate decision by the CDIO council on the acceptance of the proposals.

STANDARD 1 — THE CONTEXT*

Adoption of the principle that sustainable product, process, system and service lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education

Description

A CDIO program is based on the principle that product, process, system and service lifecycle development and deployment are the appropriate context for engineering education. Conceiving--Designing--Implementing--Operating is a model of the entire product, process, system, and service lifecycle. A CDIO education further identifies the ability to contribute to a sustainable development as a key competence of its graduates. The Conceive stage includes defining customer and societal needs; considering technology, enterprise strategy, and regulations; and, developing conceptual, technical, and business plans. The Design stage focuses on creating the design, that is, the plans, drawings, and algorithms that describe what will be implemented. The Implement stage refers to the transformation of the design into the product, process, or system, including manufacturing, coding, testing and validation. The final stage, Operate, uses the implemented product or process to deliver the intended value, including maintaining, evolving, recycling and retiring the system.

The product, process, system and service lifecycle is considered the context for engineering education in that it is part of the cultural framework, or environment, in which technical knowledge and other skills are taught, practiced and learned. The principle is adopted by a program when there is an explicit agreement of faculty to transition to a CDIO program, and support from program leaders to sustain reform initiatives.

Rationale

Beginning engineers should be able to Conceive--Design--Implement--Operate complex value-added engineering products, processes, systems and services in modern team-based environments. They should be able to participate in engineering processes, contribute to the development of engineering products, and do so while working to professional standards in any organization. This is the essence of the engineering profession. To address the issues of sustainability is a key challenge for humankind. Engineers need to understand the implications of technology on social, economic and environmental sustainability factors, in order to develop appropriate technical solutions as well as to collaborate with other actors in addressing sociotechnical issues.

STANDARD 2 — LEARNING OUTCOMES*

Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, system and service building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders

Description

The knowledge, skills, and attitudes intended as a result of engineering education, that is, the learning outcomes, are codified in the CDIO Syllabus. These learning outcomes detail what students should know and be able to do at the conclusion of their engineering programs. In addition to learning outcomes for technical disciplinary knowledge (Section 1), the CDIO Syllabus specifies learning outcomes as personal and interpersonal skills, and product, process, system and service building. Personal learning outcomes (Section 2) focus on individual students' cognitive and affective development, for example, engineering reasoning and problem-solving, experimentation and knowledge discovery, system thinking, creative thinking, critical thinking, and professional ethics. Interpersonal learning outcomes (Section 3) focus on individual and group interactions, such as teamwork, leadership, communication, and communication in foreign languages. Product, process, system and service building skills (Section 4) focus on conceiving, designing, implementing, and operating systems in enterprise, business, and societal contexts.

Learning outcomes are reviewed and validated by key stakeholders, that is, groups who share an interest in the graduates of engineering programs, for consistency with program goals and relevance to engineering practice. Programs are encouraged to customize the CDIO Syllabus to their respective programs. In addition, stakeholders help to determine the expected level of proficiency, or standard of achievement, for each learning outcome.

Rationale

Setting specific learning outcomes helps to ensure that students acquire the appropriate foundation for their future. Professional engineering organizations and industry representatives identified key attributes of beginning engineers both in technical and professional areas. Moreover, many evaluation and accreditation bodies expect engineering programs to identify program outcomes in terms of their graduates' knowledge, skills, and attitudes.

STANDARD 3 — INTEGRATED CURRICULUM*

A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, competences for sustainable development, and product, process, system and service building skills.

Description

An integrated curriculum includes learning experiences that lead to the acquisition of personal and interpersonal skills, competences for sustainable development, and product, process, system and service building skills (Standard 2), interwoven with the learning of disciplinary knowledge and its application in professional engineering. Disciplinary courses are mutually supporting when they make explicit connections among related and supporting content and learning outcomes. An explicit plan identifies ways in which the integration of skills and multidisciplinary connections are to be made, for example, by mapping the specified learning outcomes to courses and co-curricular activities that make up the curriculum.

Rationale

The teaching of personal, interpersonal, and professional skills, and product, process, system, and service building skills should not be considered an addition to an already full curriculum, but an integral part of it. To reach the intended learning outcomes in disciplinary knowledge and skills, the curriculum and learning experiences have to make dual use of available time. Faculty play an active role in designing the integrated curriculum by suggesting appropriate disciplinary linkages, as well as opportunities to address specific skills in their respective teaching areas.

STANDARD 4 — INTRODUCTION TO ENGINEERING

An introductory course that provides the framework for engineering practice in product, process, system, and service building, and introduces essential personal and interpersonal skills and the rationale of sustainability in the context of engineering.

Description

The introductory course, usually one of the first required courses in a program, provides a framework for the practice of engineering. This framework is a broad outline of the tasks and responsibilities of an engineer, and the use of disciplinary knowledge in executing those tasks. Students engage in the practice of engineering through problem solving and simple design exercises, individually and in teams. The course also includes personal and interpersonal skills knowledge, skills, and attitudes that are essential at the start of a program to prepare students for more advanced product, process, system, and service building experiences. For example, students can participate in small team exercises to prepare them for larger development teams.

Rationale

Introductory courses aim to stimulate students' interest in, and strengthen their motivation for, the field of engineering by focusing on the application of relevant core engineering disciplines. Students usually select engineering programs because they want to build things, and introductory courses can capitalize on this interest. In addition, introductory courses provide an early start to the development of the essential skills described in the CDIO Syllabus.

STANDARD 5 — DESIGN-IMPLEMENT EXPERIENCES*

A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level

Description

The term design-implement experience denotes a range of engineering activities central to the process of developing new products and systems. Included are all of the activities described in Standard One at the Design and Implement stages, plus appropriate aspects of conceptual design from the Conceive stage. Students develop product, process, system, and service building skills, as well as the ability to apply engineering science while considering aspects of sustainability, in design-implement experiences integrated into the curriculum. Design-implement experiences are considered basic or advanced in terms of their scope, complexity, and sequence in the program. For example, simpler products and systems are included earlier in the program, while more complex design-implement experiences appear in later courses designed to help students integrate knowledge and skills acquired in preceding courses and learning activities. Opportunities to conceive, design, implement and operate products, processes, and systems may also be included in required co-curricular activities, for example, undergraduate research projects and internships.

Rationale

Design-implement experiences are structured and sequenced to promote early success in engineering practice. Iteration of design-implement experiences and increasing levels of design complexity reinforce students' understanding of the product, process, system, and service development process. Design-implement experiences also provide a solid foundation upon which to build deeper conceptual understanding of disciplinary skills as well as appreciation of ethical and sustainability aspects. The emphasis on building products and implementing processes in real-world contexts gives students opportunities to make connections between the technical content they are learning and their professional and career interests.

STANDARD 6 — ENGINEERING LEARNING WORKSPACES

A combination of a physical learning environment with engineering workspaces and laboratories that support and encourage hands-on learning of product, process, system, and service building, disciplinary knowledge, and social learning, with a digital learning environment with on-line tools and environments that support and enhance the quality of teaching and student learning.

Description

The physical learning environment includes traditional learning spaces, for example, classrooms, lecture halls, and seminar rooms, as well as engineering workspaces and laboratories. Workspaces and laboratories support the learning of product, process, system, and service building skills concurrently with disciplinary knowledge. They emphasize hands-on learning in which students are directly engaged in their own learning and provide opportunities for social learning, that is, settings where students can learn from each other and interact with several groups. The creation of new workspaces, or remodeling of existing laboratories, will vary with the size of the program and resources of the institution. The digital learning environment employs digital learning technology to enhance the student learning experience as well as teaching effectiveness. Course development and delivery are assisted using appropriate e-learning development infrastructure. Program and course development is assisted by staff familiar with the CDIO framework for engineering education development, as well as expertise in instructional design, multimedia content development (recording, editing, and distribution), assessment and learning analytics.

Rationale

Workspaces and other learning environments that support hands-on learning are fundamental resources for learning to design, implement, and operate products, processes, systems and services. Students who have access to modern engineering tools, software, and laboratories have opportunities to develop the knowledge, skills, and attitudes that support product, process, and system building competencies. These competencies are best developed in workspaces that are student-centered, user-friendly, accessible, and interactive. The ability to augment learning activities through digital tools and resources provides instructors, program designers, and students with increased flexibility. Digital content repositories from prerequisite courses enable the efficient reactivation of knowledge, facilitating scaffolding across the curriculum. Program designers can structure student learning in a manner that provides increased learning flexibility including student mobility and personalized learning experience.

STANDARD 7 — INTEGRATED LEARNING EXPERIENCES*

Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, system, and service building skills.

Description

Integrated learning experiences are pedagogical approaches that foster the learning of disciplinary knowledge simultaneously with personal and interpersonal skills, and product, process, system, and service building skills. They incorporate professional engineering issues in contexts where they coexist with disciplinary issues. For example, students might consider the analysis of a product, the design of the product, as well as the social or societal responsibility of the designer of the product, all in one learning experience. Industrial partners, alumni, and other key stakeholders are often helpful in providing examples of such ~~exercises~~ cases.

Rationale

The curriculum design and learning outcomes, prescribed in Standards 2 and 3 respectively, can be realized only if there are corresponding pedagogical approaches that make dual use of student learning time. Furthermore, it is important that students recognize engineering faculty as role models of professional engineers, instructing them in disciplinary knowledge, personal and interpersonal skills, and product, process, and system building skills. With integrated learning experiences, faculty can be more effective in helping students apply disciplinary knowledge to engineering practice and better prepare them to meet the demands of the engineering profession.

STANDARD 8 — ACTIVE LEARNING

Teaching and learning based on active experiential learning methods

Description

Active learning methods engage students directly in thinking and problem-solving activities. There is less emphasis on passive transmission of information, and more on engaging students in manipulating, applying, analyzing, and evaluating ideas. Active learning in lecture-based courses can include such methods as a partner and small-group discussions, demonstrations, debates, concept questions, and feedback from students about what they are learning. Active learning is considered experiential when students take on roles that simulate professional engineering practice, for example, design-implement projects, simulations, and case studies.

Rationale

By engaging students in thinking about concepts, particularly new ideas, and requiring them to make an overt response, students not only learn more, they recognize for themselves what and how they learn. This process aims to increase students' motivation to achieve program learning outcomes and form habits of lifelong learning. With active learning methods, instructors can help students make connections among key concepts and facilitate the application of this knowledge to new settings.

STANDARD 9 — ENHANCEMENT OF FACULTY COMPETENCE*

Actions that enhance faculty competence in what to teach, including personal and interpersonal skills, product, process, system, and service building skills, competences for sustainable development, as well as disciplinary fundamentals.

Description

CDIO programs provide support for the collective engineering faculty to improve its competence in what to teach, according to program goals as described in Standard 2. This includes personal and interpersonal skills, product, process, system, and service building skills, as well as competences for sustainable development. Some of these skills are developed best in contexts of professional engineering practice. Faculty competence also includes the ability to support students to achieve a deeper working understanding of the relevant disciplinary fundamentals. The nature and scope of faculty development vary with the resources and intentions of different programs and institutions. Examples of actions that enhance faculty competence include: professional leave to work in industry, partnerships with industry colleagues in research and education projects, inclusion of engineering practice as a criterion for hiring and promotion, and appropriate professional development experiences at the university.

Rationale

If engineering faculty are expected to teach a curriculum of personal and interpersonal skills, and product, process, system, and service building skills integrated with disciplinary knowledge, as described in Standards 3, 4, 5, and 7, they as a group need to be competent in those skills. Engineering professors tend to be experts in the research and knowledge base of their respective disciplines, with only limited experience in the practice of engineering in business and industrial settings, and its role in sustainable development. A key aspect of expertise is pedagogical content knowledge, which refers to the ability to effectively support students in learning the subject. Moreover, the rapid pace of technological innovation requires continuous updating of engineering skills. The collective faculty needs to enhance its engineering knowledge and skills so that it can provide relevant examples to students and also serve as individual role models of contemporary engineers.

STANDARD 10 — ENHANCEMENT OF FACULTY TEACHING COMPETENCE

Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning

Description

A CDIO program provides support for faculty to improve their competence in integrated learning experiences (Standard 7), active and experiential learning (Standard 8), and assessing student learning (Standard 11). The nature and scope of faculty development practices will vary with programs and institutions. Examples of actions that enhance faculty competence include: support for faculty participation in university and external faculty development programs, forums for sharing ideas and best practices, and emphasis in performance reviews and hiring on effective teaching methods.

Rationale

If faculty members are expected to teach and assess in new ways, as described in the CDIO Standards, they need opportunities to develop and improve these competencies. Many universities have faculty development programs and services that might be eager to collaborate with faculty in CDIO programs. In addition, if CDIO programs want to emphasize the importance of teaching, learning, and assessment, they must commit adequate resources for faculty development in these areas.

STANDARD 11 — LEARNING ASSESSMENT*

Assessment of student learning in personal and interpersonal skills, and product, process, system, and service building skills, as well as in disciplinary knowledge

Description

Assessment of student learning is the measure of the extent to which each student achieves the intended ~~specified~~ learning outcomes. Instructors usually conduct this assessment within their respective courses. Effective learning assessment uses a variety of methods matched appropriately to learning outcomes that address disciplinary knowledge, as well as personal and interpersonal skills, and product, process, system, and service building skills, as described in Standard 2, 3 and 7. These methods may include written, online and oral tests, observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.

Rationale

If we value personal and interpersonal skills, and product, process, system, and service building skills, and incorporate them into curriculum and learning experiences, then we must have effective assessment processes for measuring them. Different categories of learning outcomes require different assessment methods. For example, learning outcomes related to disciplinary knowledge may be assessed with oral, online and written tests, while those related to design-implement skills may be better measured with recorded observations. Using a variety of assessment methods accommodates a broader range of learning styles, and increases the reliability and validity of the assessment data. As a result, determinations of students' achievement of the intended learning outcomes can be made with greater confidence.

STANDARD 12 — PROGRAM EVALUATION

A system that evaluates programs against these twelve standards and any optional standards adopted, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

Description

Program evaluation is a judgment of the overall value of a program based on evidence of a program's progress toward attaining its goals. A CDIO program should be evaluated relative to these 12 CDIO Standards and any optional standards that it has adopted. Evidence of overall program value can be collected with course evaluations, instructor reflections, entry and exit interviews, reports of external reviewers, and follow-up studies with graduates and employers. The evidence should be regularly reported back to instructors, students, program administrators, alumni, and other key stakeholders. This feedback forms the basis of decisions about the program and its plans for continuous improvement.

Rationale

A key function of program evaluation is to determine the program's effectiveness and efficiency in reaching its intended goals. Evidence collected during the program evaluation process also serves as the basis of continuous program improvement. For example, if in an exit interview, a majority of students reported that they were not able to meet some specific learning outcome, a plan could be initiated to identify root causes and implement changes. Moreover, many external evaluators and accreditation bodies require regular and consistent program evaluation.